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Comparative Study of Pitch Angle Control for Variable Speed Wind Turbine

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Abstract: Pitch angle control is commonly used method for regulating the output torque of the wind energy system whenever wind speed is exceeding base speed and other variables like wind speed, generator speed and generator power can also be selected for control. According to wind turbine power versus speed curve, generator dynamic characteristics of wind turbine system get varied. But it is essential to retain the generator speed at the ideal one despite such deviations. As PI (proportional-integral) controller is conventionally used as controller for pitch angle control, for this mathematical model of system must be already known. In this work, conventional PI controller, fuzzy logic controller and neural network based controller are implemented and their results are compared in terms of peak overshoot, settling time and offset error. The system knowledge is not required for fuzzy logic and neural network based pitch angle controller and non-linearity like wind turbulence can be easily modelled using these controllers. The simulation result shows that the neural network gives better result as compared to PI controller and fuzzy logic controller.

Key words: Wind energy conversion system, PI controller, fuzzy logic controller, neural network.

Introduction

In recent years, the fossil fuels like coal and crude oil are on the verge of exhaustion and these fuels are causing environmental pollution and problems like greenhouse effect. With these serious problems becoming bigger and bigger, a solution is gravely needed in advance so as to save environment and fossil fuel. To overcome these problems the idea of using renewable energy resources such as wind energy, solar energy etc. was invented. Wind flowing across the globe has very high potential in it. Total energy flowing through blades, area *A* during the time *t* is given by (1) (Ackermann, 2005)

$$E = A.\nu.t.\rho\frac{1}{2}\nu^2 \quad (1)$$

where 'v' is the wind velocity and 'ρ' is the air density.

The expression used here is arranged in two parts: ($A.v.t$) is actually the volume of air passing through area A, which is vertical to the wind velocity; the function $\left(\frac{1}{2}v^2\right)$ is the kinetic energy of the moving air per unit volume. Total wind power is given by (2) (Ackermann, 2005)

$$P = \frac{E}{t} = A.p.\frac{1}{2}v^3 \quad (2)$$

Wind power is directly proportional to the cube of the wind velocity; because of this wind power extracted by the wind turbine is not constant. Kinetic energy of wind is converted to mechanical energy by wind turbines. This mechanical energy is utilised to generate electricity, using generators like synchronous generator

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and induction generator. In this work, SG (synchronous generator) is used. Three bladed turbines are used in wind farms for viable production. These turbines are pointed towards wind by computer controlled motors.

Due to simple speed control method and good speed regulation characteristics generally DC motor is preferred, though its complicated structure and presence of brushes increase the probability of getting damaged (Baroudi et al., 2007; Kallio et al., 2010). Because of large power range and low price mostly asynchronous motors are preferred, but controlling method of asynchronous machine is difficult as compared to DC machine and rotor parameters are easily changed; therefore speed or torque regulation are not good (Ohyama et al., 2007; Xin et al., 2005; Salih et al., 2017). Theoretically total wind power can be calculated if the wind speed behind the turbine blades after passing through them comes to zero. In a convincing wind turbine this is difficult, as the captured air must also leave the turbine. The input and output wind velocity relation must be measured.

Another performance criterion of wind turbine power extraction is Tip Speed Ratio (TSR). The steady-state limit is based on the C_p-TSR characteristics as shown in Figure 1. At higher wind speed, the mechanical power with the optimal C_p will go beyond the nominal power for which the wind turbine is designed. It is therefore required to decrease the input mechanical power. This is attained by revolving the blades away from the direction of wind. The measure of turbine blades facing towards the wind is pitch angle and the unit of pitch angle (β) is degree.

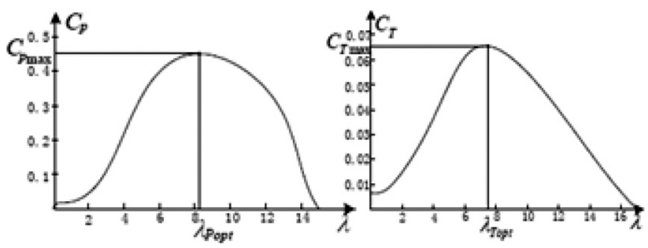

Figure 1: The curve of C_p, C_T and λ.

In Chen et al. (1998), Yao et al. (2007) and Pena et al. (1996) pitch angle control is commonly used method for regulating the aerodynamic torque of the wind turbine when wind speed is exceeding base speed and other controlling variables like wind speed, generator speed and generator power can be used. The characteristics between turbine output power and wind speed is shown in Figure 2.

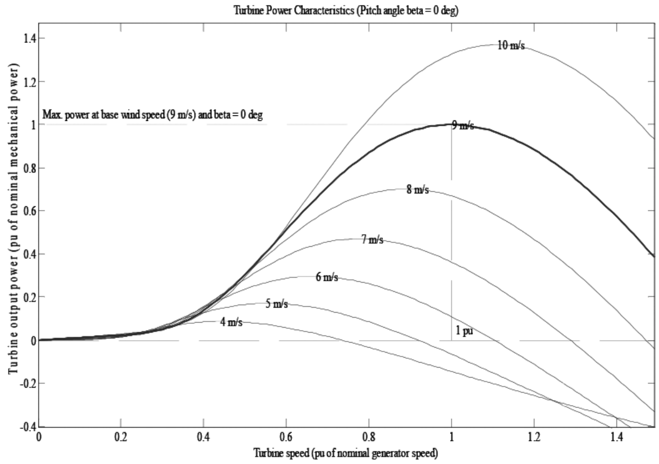

Figure 2: Turbine output vs Turbine speed (pu) as a function of pitch angle.

Analysis of Wind Turbine Characteristics

The output power and torque of wind turbine are defined in equations (3 and 4) (Ackermann, 2005)

$$P_m = \frac{1}{2} C_p(\lambda, \beta)\rho A v^3 \quad (3)$$

$$T_m = \frac{1}{2} C_T(\lambda, \beta)\rho A R v^2 \quad (4)$$

where P_m is output power, T_m—output torque, ρ—air density, A —sweep area, R —turbine rotor radius, v—wind speed, C_p (λ, β) —power coefficient and C_T (λ, β) —torque coefficient.

The torque coefficient C_T (λ, β) of the turbine is described in the following equation: $C_T(\lambda, \beta) = C_p(\lambda, \beta)/\lambda$, where β is the pitch of wind turbine and λ is tip-speed-ratio, which is defined as in (5)

$$\eta = \frac{R\omega}{v} \quad (5)$$

Pitch Angle Servo

In case of variable-speed wind turbines, pitch servo controls the blade angle. The controller decides reference angle of blade and the pitch servo is the actuator, which actually turns the turbine blades to the ordered angle. The main aim of this work is to control this pitch angle by using various controllers so that the disturbance of wind is incorporated and output power remains constant. The basic topology is given in Figure 3.

The pitch servo focuses on constructional limitations, like angular limits β_{min} and β_{max}. That means that the blades can be revolved within definite physical limits

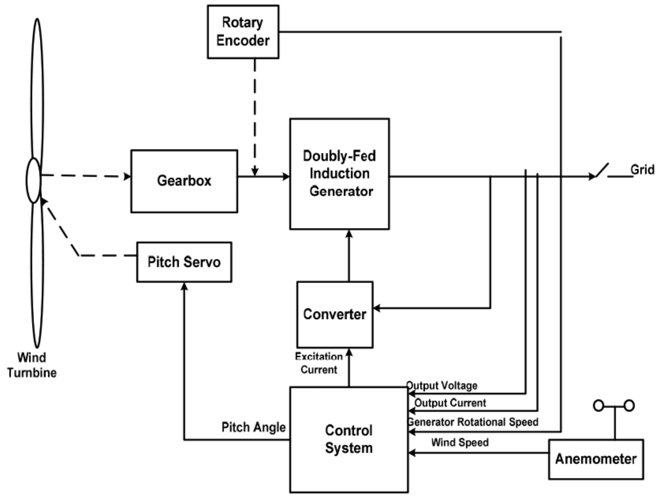

Figure 3: Pitch angle servo of wind turbine.

(Liu et al., 2008). The permissible range will be between –90° and 0° (or even a few degrees to the positive side) for active-stall-controlled wind turbines, whereas for pitch-controlled wind turbines the permissible range will vary between 0° and +90° (or even a few degrees to the negative side).

Model of a Wind Turbine with a Synchronous Generator

The block diagram for the wind energy conversion system (WECS) is discussed in Figure 3. The wind speed measured using an anemometer is used to calculate the maximum power P_{max}* which is considered as reference for the outer power control loop. The wind turbine runs the synchronous machine (SG) at the optimum speed ù$_m$ to extract the maximum power. The output voltage of variable frequency of SG is converted to DC value by using three-phase diode rectifier and is further fed to input to the buck-boost dc to dc converter. By controlling the duty cycle of boost converter the output voltage V_{dc} can be controlled at a constant level at any wind speed. The function of second PI controller is to modify the angle between the grid voltage and corresponding current in the same phase. The proposed system extracts power from wind turbine by varying the blade angle and supplies the grid. Figure 4 shows the simulation model of variable-speed wind turbines. We have used synchronous generator in this model.

Additional controllers such as rotor speed controller and pitch angle controller have been used in variable speed wind turbine; it makes variable speed wind turbine more complex as compared to constant speed turbine. Furthermore it is equipped with voltage regulator,

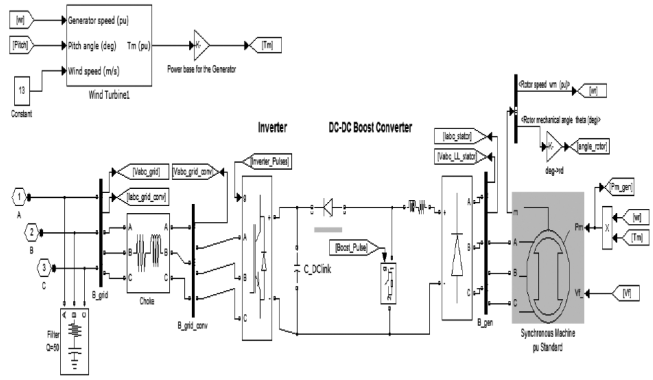

Figure 4: System architecture of wind turbine with synchronous generator.

current regulator and var controller. In this model we have used synchronous generator which is connected to AC/DC/AC converter. As we know, synchronous generator will generate three-phase power of variable frequency which is to be sent to the grid at constant frequency, for this purpose we have used two set of converters to convert the variable frequency at constant.

Pitch Control

Variable speed wind turbines can produce more power than the fixed speed ones, but this system may surpass the required power that will be delivered to the grid. We have focused on limiting the power in a variable-speed wind turbine when wind speeds exceed rated speed. The system is equipped with a SG (Synchronous Generator) connected to the grid through a diode rectifier, a braking chopper and a PWM inverter. In this model measured power is compared with reference power and the error signal is fed to the controller which will generate the pitch angle. For pitch compensation generator speed (w_r) is also compared with reference generator speed (w_{ref}) whose output is added to the controller output. MATLAB model for pitch control is shown in Figure 5.

In pitch angle control system a controller is used for controlling the pitch angle of wind turbine so that output power remains constant irrespective of increase

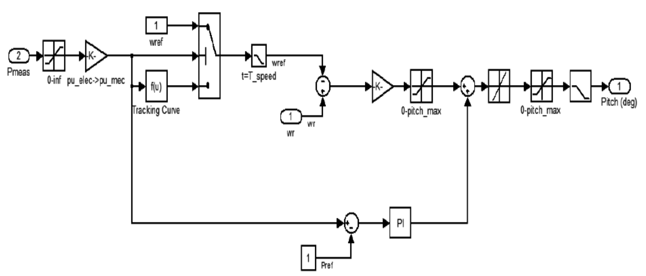

Figure 5: MATLAB model of pitch angle control.

in wind velocity which governs the output power as function of cubic equation.

Result and Discussion

The results of various controllers are obtained for the system of wind farm of 10 MW and their performances are compared with the help of MATLAB/Simulink. In the present work a wind farm is operated with its rated wind speed i.e. 11 m/s and thus wind velocity is increased to 13 m/s. So this increase in wind velocity behaves as the disturbance to the plant (wind farm). According to the laws of wind energy system, when wind velocity changes, the output power will change as a function of cube but the pitch angle controller is used here for reduction in the excess power extracted from wind. In response to this wind gust a conventional PI control (as shown in Figure 5) is employed to the wind farm. When this PI controller is tuned then it works as primary control of output power of wind farm to its rated value. The response of PI controller is given in Figure 6.

To improve the response to the disturbance a fuzzy logic controller is first designed as elaborated and implemented to the wind turbine generator pitch servo mechanisms. When a wind disturbance of same intensity as used in with conventional controller is given to wind farm with fuzzy logic controller then its power output response is obtained and shown in Figure 7.

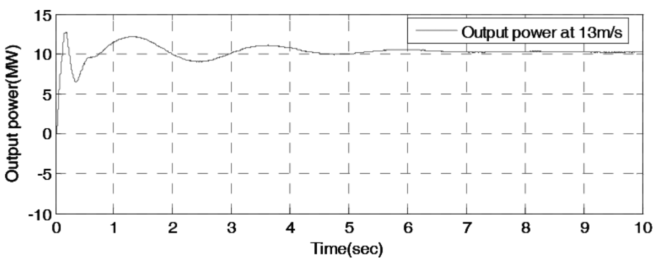

Figure 6: Power output with conventional PI control.

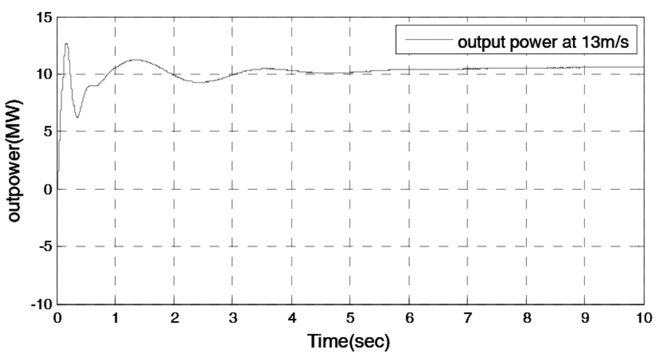

Figure 7: Power output using fuzzy logic controller.

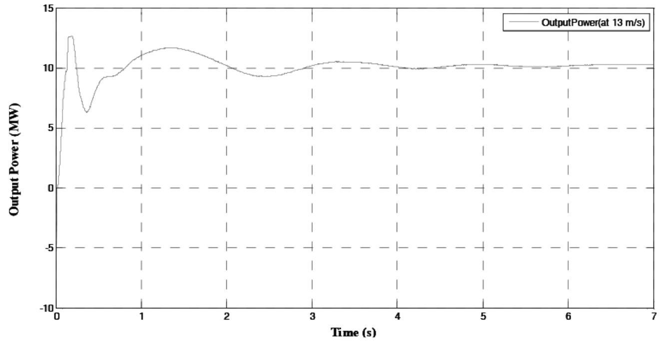

Figure 8: Power output using neural network controller.

When a neural network controller is implemented instead of conventional PI controller the results for the same disturbances is obtained by simulating the system and the result as shown in Figure 8. The training of neural network reached the 10% of the specified goal of the error. The two basic parameters of wind turbine i.e. power output in Mega Watts and pitch angle in degrees are calculated.

Comparison

The comparison of PI with fuzzy is shown in Figure 9. The PI controller has less peak overshoot then fuzzy logic controller but settling time is reduced (5.932 sec) in fuzzy logic controller and there is more offset error

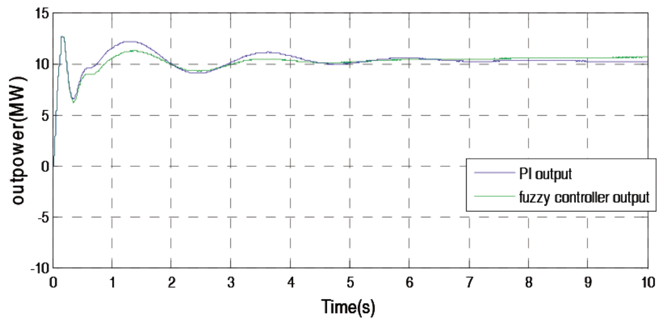

Figure 9: Comparison of PI controller with fuzzy controller.

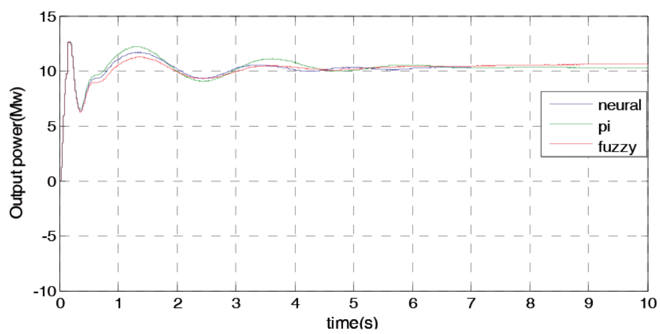

Figure 10: Comparison of PI, fuzzy logic and neural control.

(.61) in case of fuzzy logic controller compared to PI controller, but oscillations are reduced in fuzzy logic controller.

The comparison of conventional control with fuzzy, neural is done to discuss the performance of new controllers on the basis of basic performance criteria of control system i.e. peak overshoot, settling time and offset. Fuzzy controller has some offset error than conventional controller, but settling time is less than conventional controller and offset error is reduced in neural control. Neural controller has less settling time (4.30 sec) than fuzzy logic controller and PI controller and offset error (.22) is also minimized. The comparisons of PI with fuzzy and neural are shown in Figure 10.

All the controllers are designed and implemented in wind energy system for pitch angle control and their performances in terms of output power peak overshoot, settling time and offset error are compared. This comparison is given in Table 1.

Table 1: Comparison of performances of intelligent controllers

Controller	*Peak overshoot (%)*	*Settling time (sec)*	*Offset error*
PI	26.6	6.934	0.23
Fuzzy logic	26.1	5.932	0.6
Neural	26	4.3	0.22

Conclusion

In order to handle the output power when wind speed is above the base speed, pitch angle control is proposed. In the higher wind speed region, the rotor speed must be controlled to avoid increased speed in rotor beyond a controllable limit.The pitch angle is kept at its optimum value. The C_p is maintained at its maximum value as the wind speed varies. The accelerating and decelerating mode are easy to control if the difference between the electrical power and aerodynamic power may be minimized. The capability of controller to control the pitch angle is important to shed the extra aerodynamic power.Conventional PI controller, rule based fuzzy logic controller and neural network controller are simulated and their results are compared. From Table 1 it is clear that neural network gives better result as compared to conventional PI and fuzzy. There is also scope of control when wind speed is below the rated speed using the boost converter scheme.

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